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RADIATION EXPOSURE OVERVIEW

Nuclear Power Reactors and the Population

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
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RADIATION EXPOSURE OVERVIEW

NUCLEAR POWER REACTORS AND THE POPULATION

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service
Environmental Health Service
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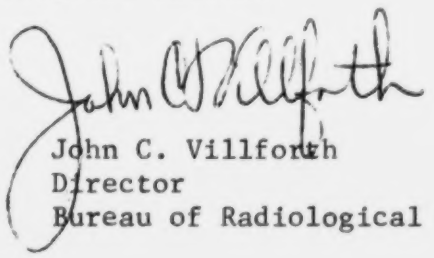
FOREWORD

The significance of a specific source of radiation and whether efforts directed towards its control are effective, depend, in large part, on an assessment of the magnitude of radiation exposure received by a population from that source. The process of assessment includes comparing estimates of exposure against pertinent guidance or standards. These comparisons provide reference points for radiation control programs.

Radiation exposure overviews are designed both to highlight these points of reference as well as identify needed information. Developed from available, salient information, each overview seeks to relate an observed or potential radiation experience or exposure of a population group with a radiation source. Relevant guidance or standards and the status of exposure control efforts, where such data are available, are also incorporated.

Radiation exposure overviews are prepared by the Office of Criteria and Standards with the assistance of the Divisions and Offices of the Bureau of Radiological Health.



John C. Villforth
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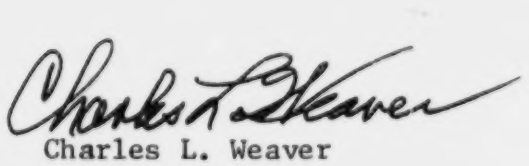
PREFACE

The Bureau of Radiological Health has been established as the focal point for radiological health activities within the Public Health Service. The Bureau's Division of Environmental Radiation has been assigned the responsibility for the technical review and evaluation of the public health factors of all types of nuclear facilities and to provide technical assistance to State Health Departments responsible for assessing radiation levels in the environment. This technical review procedure was initiated in 1961, based on an interagency agreement between the Atomic Energy Commission and the Department of Health, Education, and Welfare. This agreement established the mechanism whereby the Atomic Energy Commission's Division of Reactor Licensing provides to the Division of Environmental Radiation copies of the Design Safety Analysis Reports, and amendments thereto, submitted by the various applicants proposing to build and operate nuclear facilities. The Nuclear Facilities Branch within the Division of Environmental Radiation evaluates these reports from a public health viewpoint, and submits findings and recommendations to the State health agency responsible for the environmental health aspects of the plant.

The Division of Environmental Radiation provided the Office of Criteria and Standards with technical assistance and consultation in the development of this overview. The objective of this overview is to provide individuals or organizations with information regarding the radiological health aspects of nuclear power reactors. In addition to broadly documenting the exposures associated with this source of radiation, information presented may be useful for comparing the estimated radiation exposure of the public with that from other sources of environmental exposure. Data are included on the quantities of radioactivity discharged from nuclear power reactors to the environment and comparisons are made with applicable radiological health standards.

The author is a member of the Office of Criteria and Standards.



Charles L. Weaver
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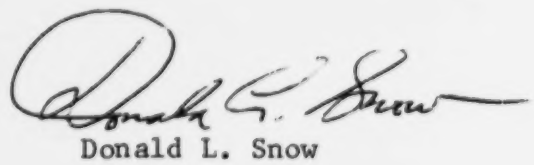

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NUCLEAR POWER REACTORS AND THE POPULATION

INTRODUCTION

At the end of June 1969, there were approximately 3,250 megawatts electric (MWe) gross generating capacity from nuclear power in the United States (1). This generating capacity was largely produced by 11 civilian owned nuclear power reactors. There were an additional 86 nuclear power plants under various stages of planning or construction. The Atomic Energy Commission has predicted that by 1980 there will be a generating capacity of 120,000 to 170,000 MWe in the United States which will represent approximately 25 percent of the total electrical power generated during that year (2). It has also been estimated that the nuclear generating capacity may be further increased to 1,000,000 MWe by the year 2000 (3). Factors responsible for the increase in nuclear generated electricity include (a) increase in the demand for electricity in the United States, (b) recognition that large nuclear power plants are economically competitive with fossil fuel plants for producing electrical power in some areas of the country, and (c) a limited number of hydroelectric power sites remaining for development.

Two types of reactors currently dominate the U.S. nuclear power industry. These are the pressurized-water reactors (PWR) and the boiling-water reactors (BWR). By the end of June 1969, there were five PWR's and five BWR's producing over 70 percent of the nuclear generated electrical power in the United States (1). Also at that time there were 31 BWR's and 43 PWR's being planned or under construction.

In addition to the PWR's and BWR's there are several types of convertor reactors and breeder reactors in various stages of development. Convertor reactors produce some fissionable material but less material than they consume while breeder reactors produce more fissionable material than is required for their operation. The convertor reactors, which include gas-cooled reactors and organic-cooled and moderated reactors, show considerable promise for more economical power because of higher operating efficiencies (4). Breeder reactors are the ultimate goal of the nuclear power industry. By using non-fissile uranium and thorium as fuel, these reactors will extend the world's nuclear fuel resources.

By 1975, at least 30 States will have civilian nuclear power reactors operating within their respective boundaries (see figure 1), the greatest concentration of which will be in the north-central and northeastern regions of the country. At the present time, no nuclear power plants are operating in the southeastern region although there are seven reactors under construction and 10 more in various stages of planning.

The nuclear reactors that are being built and those planned for the future will generally operate at substantially higher power levels than those reactors currently in operation. These larger reactors will contain a greater core inventory of fission products which is a factor tending to increase the potential hazard to the population in case of accidental releases of radioactivity. Also, the increase in orders for nuclear reactors has resulted in plans for placing more than one reactor at existing or future sites. A number of reactor sites may be located so that there will be a utilization of a common receiving body of water and the same local air and terrestrial environment (5). The establishment of specific radioactive effluent discharge limits applicable to such conditions may be required to assure that the total dose to the population is within the guidance of the Federal Radiation Council.

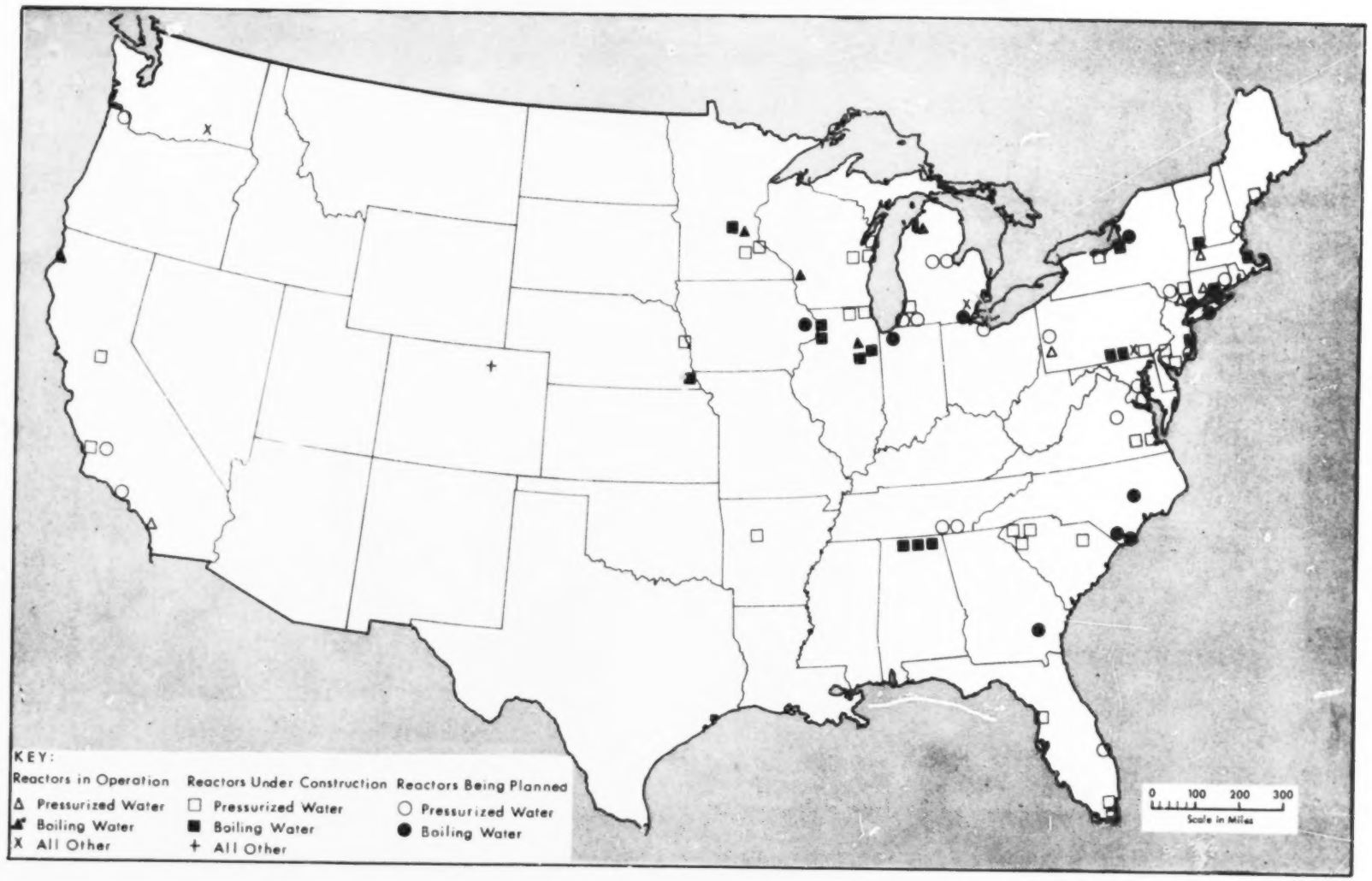

Figure 1. Nuclear Power Plants in the United States. (1)

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RADIATION EXPERIENCE

EXPOSURE FACTORS

Sources of Radioactive Waste

The nature and amount of wastes resulting from the operation of a nuclear reactor depends on the type of reactor and the waste management practices at the facility. However, the radioactive wastes stemming from reactor operations are the result of two general processes: (1) fission and (2) neutron activation of the coolant, impurities in the coolant, and structural components of the reactors.

Fission products are the predominant source of radioactivity in a nuclear power plant and they remain, to a large extent, within the fuel elements in which they originate until chemically removed at a fuel reprocessing plant. Reactors now in operation and those planned for the future are typified by a core lattice of fuel elements clad with a structural material to contain fission products and to protect the fuel from the coolant. During operation, cladding leaks occasionally occur and small amounts of fission products escape into the coolant. Also, in the manufacture of fuel elements the outer surface of the cladding may become contaminated with uranium in addition to the occurrence of uranium in the cladding as an impurity (6). This "tramp uranium" gives rise to minimal quantities of fission products whose movement within the primary system is not inhibited by the fuel cladding. There is also evidence that some of the ternary fission product tritium and noble gases that originated in the fuel elements will be present in the coolant as a result of diffusion through fuel claddings (7). Some of the principal fission products that may be found in the primary coolant are ^{133}Xe, ^{135}Xe, ^{85}Kr, ^{131}I, ^{89}Sr, ^{137}Cs, ^{133}I, ^{135}I, and ^{3}H, among others (7,8).

Radionuclides also appear in the coolant of nuclear reactors as a result of neutron activation. A major source of radioactivity in the coolant of some of the reactors is the oxygen contained in the coolant itself. There are several nuclear reactions involving oxygen that lead to the production of nitrogen radioisotopes. Fortunately, these activation products have short physical half-lives and therefore are of little significance as potential environmental contaminants. Activation

products may also appear in the coolant as the result of neutron activation of structural materials in the reactor core and subsequent corrosion or from the corrosion of primary system materials and subsequent transport to the core area where they become irradiated. Some of the activation products that may be present in the coolant through corrosion and erosion may include ^{58}Co, ^{60}Co, ^{54}Mn, ^{59}Fe, ^{51}Cr, and ^{65}Zn (8).

Tritium may also appear in the primary coolant of light-water reactors as an activation product. Large PWR's may use boron compounds in their primary coolants for reactivity[1] control. In these systems, tritium will be produced by neutron reactions with the boron nucleus (9). Tritium may also be produced in various quantities in nuclear power reactors by (a) neutron capture reactions with lithium which is sometimes added for pH control, (b) neutron activation of naturally occurring deuterium in the coolant water, and (c) high energy neutron capture reactions with structural materials (10).

The radionuclides identified in the primary coolant are of significance since they serve as an indication of the radionuclides contained in discharges to the environment. The relationship between the levels of radioactivity in the reactor coolant and those in the discharged waste depends on the waste management of a particular plant. The general philosophy of waste management is to concentrate and contain radionuclides with minimal releases to the environment. Although waste management systems differ between power plants, there are similarities among boiling-water reactors on one hand and pressurized-water reactors on the other. The methods for treating radioactive wastes have been previously discussed in detail for both types of reactors in references (11,12).

Radioactivity in Effluent Air and Water

All operating nuclear power plants routinely discharge small quantities of gaseous and liquid radioactive wastes to their environs. Solid radioactive wastes, including spent fuel elements, are stored at the site for periodic shipment offsite for reprocessing or permanent disposal. These practices will be continued by the larger nuclear power plants that are now under design or construction.

In a boiling-water reactor, the light-water coolant is circulated through the reactor core where it boils under high pressure. The generated steam is then passed through the turbine and returned to the core. An ejector continuously removes the noncondensable gases from the turbine condenser and discharges them through an off-gas system,

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[1]Reactivity is a measure of the departure of a nuclear reactor from criticality.

generally comprised of a delay line and filter system, and then through a tall stack to the environment.

In a pressurized-water reactor, the coolant is not passed through the turbine but is used to form steam in an intermediate cooling loop that drives the turbine. Gases generated within the primary system are retained and vented at intervals to a waste system where they may be held up for as long as 60 days for radioactive decay before being discharged into the environment.

Because of the basic design differences between boiling-water and pressurized-water reactors, there are variations in both the radioactivity levels and the radionuclide composition of the gaseous effluents from the two types of plants. The boiling-water reactors normally discharge much larger quantities of radioactivity than do pressurized-water reactors. However, the radioactivity in the discharged wastes from boiling-water reactors is mainly attributed to short-lived noble and activation gases while the gaseous effluents from pressurized-water reactors are mainly composed of radionuclides having relatively long half-lives (i.e. ^{85}Kr and ^{133}Xe).

Annual discharges of gaseous radioactive wastes for 1967 and 1968 are summarized in table 1 for five pressurized-water and three boiling-water reactors. An interesting aspect of the data is the large range of values, covering over eight orders of magnitude. The gaseous discharges for the BWR's ranged from 144,500 curies at Big Rock Point in 1968 to 900,000 curies at Humboldt Bay during 1967. The annual discharges for the PWR's varied from 0.001 curie at Shippingport in 1968 to 55.2 curies at Indian Point during that same year.

No apparent relationship was found between the power level and the gaseous emission rate of seven light-water reactors (13). The PWR's discharge rates ranged from $2X10^{-5}$ to $2X10^{-3}$ μCi/sec per megawatt thermal (Mwt). The discharge rates for the BWR's varied between 24 and 80 μCi/sec per Mwt, with the smaller plants having the higher rates.

The data presented in table 2 reflect the contribution of the noble and activation gases and the halogens and particulates to the gaseous wastes from nuclear power plants. The effluent releases are comprised almost entirely of noble and activation gases. At some nuclear plants, gaseous wastes are routinely passed through high-efficiency filters before being discharged into the atmosphere. The gaseous wastes from these plants are virtually free of radioactive particulate matter during normal operation (18).

Liquid radioactive wastes resulting from the operation of nuclear power reactors may be treated in many ways before being discharged into the uncontrolled environment. The more common methods used may include

Table 1. Annual gaseous radioactivity discharges from nuclear power reactors[a]

Nuclear Power Plant	1967 (Curies)	1968 (Curies)
Indian Point I[b]	23	55.2
Yankee[b]	2.3	0.66
Connecticut Yankee[b]	0.02	3.7
San Onofre[b]	4	4.75
Shippingport[b]	0.002	0.001
Big Rock Point[c,d]	264,000	144,500
Dresden I[c]	191,000	240,000
Humboldt Bay[c]	900,000	897,000

[a]Data from references (14-17)

[b]Pressurized-water reactor

[c]Boiling-water reactor

[d]Report year runs from November 1 through October 31

Table 2. Nuclear reactor discharge rates of activation and noble gases and of halogens and particulates[a]

Nuclear power plant	Activation and noble gases (μCi/second)	Halogens and particulates (μCi/second)
Dresden I[b]	$< 10^2$ to $2.5X10^4$	$2X10^{-3}$ to $3X10^{-3}$
Big Rock Point[b]	< 20 to $3.5X10^4$	< 1.2
Humboldt Bay[b]	40 to $2.8X10^4$	10^{-5} to $7X10^{-2}$
Elk River[b]	0 to $1.1X10^2$	$< 3X10^{-5}$
Indian Point I[c]	0.07 to 1.6	$\sim 2X10^{-8}$

[a]Data from reference (7)

[b]Boiling-water reactor

[c]Pressurized-water reactor

ion-exchange or demineralization, evaporation, and filtration followed by dilution of the effluents (19). High volume and low-contamination liquid wastes, such as those resulting from laundry operations, may be stored and then monitored prior to release without any other treatment.

The liquid waste volumes handled at nuclear power plants are not large (2,000 to 45,000 gallons per day) in comparison to the volumes of liquid wastes from many other types of industries (20). Normally, only small amounts of radionuclides are contained in the discharged liquid wastes and estimates show that tritium may comprise between 50 and almost 100 percent of the total radioactivity in the liquid wastes (21). This fact is reflected in reported discharges from the Yankee-Rowe reactor that have recently averaged approximately 100 curies per month of tritium in the liquid wastes, some four orders of magnitude higher than the other radioactive material releases (7). These tritium discharges represent a small fraction of the applicable health and safety standard (See "Compliance").

Liquid effluent releases of radioactivity (excluding tritium) to surface waters during 1967 and 1968 are shown in table 3 for three BWR's and five PWR's. The discharges of radioactive liquid wastes varied between 0.009 curie at Yankee in 1968 and 36.7 curies at Indian Point I during that same year. Most power plants exhibit discharges well below those of the Indian Point pressurized-water reactor; for example, from October 1961 until January 1966, a total of 0.05 curie of radioactivity (excluding tritium) was released into the Mississippi River from the Elk River power plant (22).

In the past, liquid wastes generated by nuclear reactors were not routinely monitored for tritium. However, recent estimates have been made of the annual tritium releases from six nuclear power stations (table 4). Dresden I, Big Rock Point, Humboldt Bay, and Elk River are BWR's, while Yankee-Rowe and Indian Point I are PWR's. The estimates show that 5 to 20 curies of tritium are released annually by each of the BWR's and about 500 to 1,300 curies are discharged annually at Indian Point and Yankee-Rowe, respectively (7). Tritium is also contained in the discharged gaseous wastes from both pressurized- and boiling-water reactors. The amount of tritium released in gaseous form, however, appears to constitute only about 1 percent of the total tritium discharged from a light-water reactor (10).

The solid wastes created in the normal operation of nuclear power reactors vary widely in nature, volume, and activity level. These wastes will not be considered here since they are not released to the uncontrolled environment but are stored on site or are disposed of through commercial land burial operations in Illinois, New York, Kentucky, Nevada, and Washington (23).

Table 3. Annual liquid radioactivity discharges from nuclear power reactors in curies (excluding tritium)[a]

Power Plant	1967 (Curies)	1968 (Curies)
Shippingport[b]	0.07	0.08
Indian Point[b]	28	36.7
Connecticut Yankee[b]	0.39	3.8
San Onofre[b]	0.32	1.5
Yankee[b]	0.056	0.009
Big Rock Point[c]	10	7.9
Dresden I[c]	4.3	5.97
Humboldt Bay[c]	3.1	3.2

[a]Data from references (14 and 17)

[b]Pressurized-water reactor

[c]Boiling-water reactor

Table 4. Estimated annual tritium discharge in liquid wastes[a]

Power Plant	Tritium released (Ci/year)
Dresden I[b]	5-10
Big Rock Point[b]	20
Humboldt Bay[b]	20
Elk River[b]	10
Indian Point I[c]	500
Yankee-Rowe[c]	1300

[a]Data from reference (7)

[b]Boiling-water reactor

[c]Pressurized-water reactor

Environmental Exposure

The radiation doses received by individuals in the vicinity of a nuclear facility may result from a variety of exposure pathways (24,25). The significance of each pathway is dependent on such factors as the type of discharged waste, the radionuclide composition and radioactivity levels of the discharged wastes, population characteristics, and use of the offsite environment. Usually only some of the possible exposure pathways will apply to each nuclear reactor site since each site is a separate, unique entity.

Particulates and gaseous radioactive waste discharged to the atmosphere are subject to physical and meteorological phenomena such as diffusion, sedimentation, inversion, and wind movement (26). The particulate airborne wastes may be deposited on the soil and vegetation, resulting in the contamination of certain human or animal food resources by direct deposition or through the plant uptake of radioactive materials from the soil. In some cases the exposure pathway represents the direct irradiation from radionuclides in the surrounding environment; for example, individuals in the proximity of a nuclear power plant may receive whole-body external exposures from such noble gases as krypton 85 -- that are discharged to the atmosphere.

There are several pathways by which radioactive waste discharged into surface waters by nuclear reactors may reach the surrounding population -- this radioactivity may result in an internal exposure to the population if the water receiving the liquid effluents is used for drinking or culinary purposes. Also, fish and shellfish have the ability to concentrate certain radionuclides (25,27); therefore some of the radionuclides contained in the discharged liquid waste may reach man through the human consumption of fish or shellfish from contaminated waters. Individuals in the population may also be exposed to a certain degree from (a) consumption of food crops irrigated with contaminated water and (b) extensive use of contaminated water for recreational purposes (8).

In order to evaluate the extent of reactor contamination of the environment, routine offsite surveillance programs are being conducted by facility operators and State public health agencies on either a cooperative or unilateral basis (28,29). Although the specific programs may vary from site to site, the samples collected and analyzed for radionuclide content may be placed in three general categories: air, water, and terrestrial (28). The principal objectives of environmental surveillance around nuclear facilities have been previously described in detail along with a proposed minimum program to meet these objectives (29-31). This program includes recommendations of the vectors to be sampled, the frequency of sampling, and the type of analyses needed.

The routine radiological data gathered from these surveillance programs, when combined with appropriate exposure pathways, may provide a basis for estimating population exposure. The contribution of natural radioactivity and fallout from nuclear weapons tests to the environmental surveillance data must be considered before population exposures are attributed to effluent discharges from nuclear reactors. Taking this factor into consideration, actual monitoring of the offsite areas around nuclear reactors indicates that effluent discharges from reactors generally contribute very little to environmental radiation levels (32). While external exposures resulting from gaseous effluents were detected in the offsite environs of a boiling-water reactor, data from other environmental samples obtained at the same reactor show that radioactivity was not measurable in the food or water exposure pathways (33).

DOSE ESTIMATES

The evaluation of potential radiation doses received by the population residing in proximity to nuclear power reactors has been primarily concerned with the accidental releases of radioactivity. These studies directly influence the selection of the reactor site and engineered safeguard requirements of the facility (34).

Current literature contains only a limited number of measurements or estimates of radiation doses resulting from the radioactive effluents of normal operating nuclear reactors. The average annual whole-body dose rate received by individuals living near the site boundaries of 10 of the operating power reactors, based on results obtained from environmental radiation surveillance programs, has been estimated to be generally less than 5 mrem (14). Preliminary results from a study conducted at the Dresden boiling-water reactor indicate that offsite external exposure at this power plant may vary between 5 and 15 mrem per year (33). At the Humboldt Bay boiling-water reactor, the maximum integrated doses above background measured offsite were 50 mrem in 1965 and 35 mrem in 1966 (7). The offsite doses resulting from pressurized-water reactor operations have been estimated to be less than those from boiling-water reactors (9).

EXPOSURE CONTROL

RECOMMENDATIONS, STANDARDS, AND REGULATIONS

The regulation of nuclear power reactors has been interpreted to be solely within the jurisdiction of the U.S. Atomic Energy Commission (AEC) as described in the Code of Federal Regulations, Title 10 (35).

> Interpretation by the General Counsel: AEC jurisdiction over nuclear facilities and materials under the Atomic Energy Act (36).
>
> "By virtue of the Atomic Energy Act of 1954, as amended, the individual States may not, in the absence of an agreement with the Atomic Energy Commission, regulate the materials described in the Act from the standpoint of radiological health and safety. Even States which have entered into agreements with the AEC lack authority to regulate the facilities described in the Act, including nuclear power plants and the discharge of effluents from such facilities, from the standpoint of radiological health and safety."

The approach used in promulgating regulations which restrict the radiological contamination of the environment has been to avoid all unnecessary human exposure to radiation. This philosophy has been endorsed by the Federal Radiation Council (37) and the National Council on Radiation Protection and Measurements (38).

Nuclear power plants are licensed by the AEC with respect to the discharge of liquid and gaseous radioactive wastes to the environment. The following criteria, found in Title 10, Part 20, (10 CFR 20), are utilized in establishing discharge limits.

> 10 CFR 20.105, Permissible Levels of Radiation in Unrestricted Areas states that the Atomic Energy Commission (AEC) "will approve the proposed limits if the applicant demonstrates that the proposed limits are not likely to cause any individual to receive a dose to the whole body in any one calendar year in excess of 0.5 rem." Two further limits are

placed upon radiation exposure in unrestricted areas, radiation levels are prohibited that (1) "....result in an individual receiving a dose in excess of 2 millirems in any one hour" or (2) "....result in an individual receiving a dose in excess of 100 millirems in any 7 consecutive days."

10 CFR 20.106, Radioactivity in Effluents to Unrestricted Areas states that "a licensee shall not release to an unrestricted area radioactive material in concentrations which exceed the limits specified in Appendix B, Table II of this part." The concentration limits in Appendix B, Table II shall apply at the boundary of the restricted area for gaseous wastes and at the point of discharge into receiving waters for liquid wastes. 10 CFR 20.106 also stipulates that "the Commission may limit quantities of radioactive materials released in air or water during a specified period of time if it appears that the daily intake of radioactive material from air, water, or food by a suitable sample of an exposed population group, averaged over a period not exceeding one year, would otherwise exceed the daily intake resulting from continuous exposure to air or water containing one-third the concentrations of radioactive materials specified in Appendix B, Table II of this part."

The licensed gaseous discharge limits vary from reactor to reactor because of the differences in meteorological and other environmental and physical factors that pertain to each site. Discharge to the atmosphere at a concentration higher than the limiting concentrations is possible if advantage can be taken of the dilution or dispersion of the gaseous effluent. This requires control of the discharge rate, knowledge of meteorological conditions in the area, and monitoring of the site boundary and the surrounding environment to insure that the dispersed radioactivity concentrations are less than the permitted maximum.

Other standards and recommendations for interpreting environmental levels of radioactivity have been promulgated by the Federal Radiation Council (FRC), the Public Health Service (PHS), the International Commission on Radiological Protection (ICRP), and the National Council on Radiation Protection and Measurements (NCRP).

The FRC has established intake values for strontium 90, strontium 89, radium 226, and iodine 131 (39). A graded scale of action is recommended when the intake from each of these radionuclides reaches a prescribed level. The FRC recommends that the daily human intake for

these radionuclides, averaged over periods on the order of a year, should not exceed the appropriate upper limit of Range II, a range requiring quantitative surveillance and routine control (39).

The Public Health Service has recommended limits for minimum surveillance on the concentration of radium 226 and strontium 90 in drinking water (40). Also included in these recommendations is an upper limit of 1,000 pCi/liter for gross beta radioactivity in water when neither strontium 90 nor alpha particle emitters are present. These recommended standards should be given consideration when assessing the radiological acceptability of contaminated water resources that may be used as a public drinking water supply.

The NCRP and the ICRP have recommended maximum permissible concentration values (MPC) for water and air for occupational exposures (38,41). With suitable reductions, these MPC's may be applied to the general population. The concentration limits contained in Appendix B, Table II of 10 CFR 20 are based on FRC guides when given, or on one-tenth of the recommended occupational MPC's of the NCRP and the ICRP when FRC guidance is lacking.

COMPLIANCE

Data consulted in the preparation of this report indicate that all "on line" nuclear power stations have controlled their discharges of radioactive wastes so that exposure of the general population from this source of radiation has been well within applicable health and safety standards.

The data in table 5 demonstrates the degree of compliance with AEC regulations for gaseous effluents during 1967 and 1968 for seven nuclear power plants. During the 2-year period, only two of the reactors exceeded 1 percent of their licensed discharge limits for noble and activation gases. Dresden operated at 1.1 percent of its licensed limit during 1968 while Humboldt Bay discharged noble and activation gases at a rate equal to 57 percent of its licensed limit during both 1967 and 1968. With the exception of Humboldt Bay, each of the power plants released halogens and particulates at less than 1 percent of their discharge limits.

The data from five nuclear power plants, presented in table 6, reflect the degree of compliance with the concentration limit for unidentified radionuclides contained in liquid wastes. The radioactivity concentrations in the discharge canal are generally a small percentage of the concentration limit (10^{-7} μCi/ml). While tritium may comprise between 50 and nearly 100 percent of the total activity in the

liquid wastes, the concentrations are normally less than 1 percent of the limit for tritium ($3X10^{-3}$ μCi/ml) as specified in 10 CFR 20 (10). In some cases, the power facilities have not taken credit for the individual radionuclides identified in liquid wastes that would further increase the permissible quantities that could be discharged (20).

Table 5. Annual discharges of gaseous radioactive wastes from nuclear power reactors as a percentage of the licensed discharge limits[a]

Nuclear Power Plant	Percentage of discharge limit for activation and noble gases		Percentage of discharge limit for halogens and particulates	
	1967	1968	1967	1968
Indian Point I[b]	<1	<1	<1	<1
Yankee[b]	<1	<1	<1	<1
Connecticut Yankee[b]	<1	<1	<1	<1
San Onofre[b]	<1	<1	<1	<1
Big Rock Point[c]	<1	<1	<1	<1
Dresden I[c]	<1	1.1	<1	<1
Humboldt Bay[c]	57	57	11	8

[a]Date from reference (14) and adapted from references (15,16)

[b]Pressurized-water reactor

[c]Boiling-water reactor

Table 6. Radioactivity concentrations in the discharge canals of nuclear power reactors as a percentage of concentration limit for unidentified radionuclides[a]

Nuclear power plant	Percentage of limit[b]							
	1960	1961	1962	1963	1964	1965	1966	1967
Shippingport[c]	3.8		2.4	3.5	7.6	2.5	2.4	
Yankee[c]	0.01	0.03	0.03	0.01	0.01	0.11	0.13	0.20
Indian Point I[c]			0.2	0.3	21.7	43.		
Dresden[d]	5.4	6.3	8.0	8.4	11.8	27.3	35.4	
Humboldt Bay[d]				2.7	2.7	9.3	11.8	17.4

[a]Data adapted from reference (42)

[b]Concentration limit (10^{-7} μCi/ml) for unidentified radionuclides as given in 10 CFR 20

[c]Pressurized-water reactor

[d]Boiling-water reactor

ANALYSIS AND COMMENTS

While nuclear power reactors contain large inventories of radioactive materials, the effluent discharge data indicate that they discharge only small quantities of radioactive wastes in comparison to their licensed limits under normal operating conditions. This situation is a result of careful waste management practice, engineered safeguards, and proper operating procedures. Only tritium and inert gases do not respond to conventional waste treatment processes and therefore are usually the only radionuclides that are discharged in any significant quantities. These radionuclides have been discharged, however, at rates well below those specified by the AEC.

Radiation dose estimates resulting from the radioactive effluents of three nuclear power reactors for various periods of time are compared with doses from natural background radiation in table 7. Since the procedures for estimating the doses from the operation of these nuclear power plants were not discussed in the literature, it is assumed that these data represent, at best, gross estimates. However, it appears that for normal operating conditions the population exposure from nuclear power plants represents only a small fraction of the exposure resulting from natural background radiation and also is well within the limits of the recommended radiation protection standards.

While the biological effects from high doses of ionizing radiation are known, it is extremely difficult to establish evidence that demonstrates deleterious bioeffects resulting from low-level radiation exposures. Because it is as difficult to establish evidence to the contrary, human exposure to ionizing radiation without expectation of counterbalancing benefits should be avoided. In considering the useful application of nuclear generated electrical power, it is difficult to assess the benefit in relation to the radiation exposure risk. However, the FRC, the NCRP, and the ICRP have recommended substantially uniform guidance to limit the radiation exposure risk to the public. Current opinion holds that as long as the human doses from nuclear reactor effluents are well within the presently established radiation protection guidance it can be assumed that the exposure risk will be small.

All organizations concerned with public health and safety should be cognizant of future environmental contamination by nuclear power reactors. This may be particularly important when an expanding nuclear

industry results in the overlapping and interaction of several reactor areas of influence. For example, in the future several nuclear reactors may share the same local environment and there must be an assurance that a buildup of radioactivity in the environment will not exceed acceptable health and safety standards. As a first step towards insuring against this buildup of radioactivity and to help minimize unnecessary human exposure, there should be a continuation of environmental surveillance programs and interpretation of the radiological data from such programs. While helping to verify the adequacy of source control, these environmental surveillance programs will also provide a source of information for the public to use in assessing the benefits derived from nuclear power.

From the standpoint of radiological health, consideration should also be given to the potential environmental contamination by fuel reprocessing plants. Reprocessing of the spent fuel from nuclear reactors may result in environmental radioactivity levels far greater than those associated with the reactors themselves because of the substantial inventories of fission products in the unencapsulated fuel.

Table 7. Comparison of offsite dose estimates from nuclear power reactors with dose estimates from natural background radiation

Reactor Site	Reference organ	Estimated radiation dose[a]	Period of time	Radiation dose from natural background[b]
Humboldt Bay	whole body	35 mrem 50 mrem	1966 1965	100 mrem
Dresden	whole body	5 to 15 mrem/year		100 mrem/year
Nuclear power reactors in general	whole body	<5 mrem/year		100 mrem/year

[a]Estimates from references (7,14 and 33)

[b]Whole-body dose estimate from reference (43)

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William H. Oates, Jr., January 1970
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